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Measurements of the Viscosities of Saturated and Compressed Fluid 1-Chloro-1,2,2,2-Tetrafluoroethane (R124) and Pentafluoroethane (R125) at Temperatures Between 120 and 420 K

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The shear viscosities of saturated and compressed fluid 1-chloro-1,2,2,2-tetrafluoroethane (R124) and pentafluoroethane (R125) have been measured with two torsional crystal viscometers at temperatures between 120 and 420 K and at pressures up to 50 MPa. At small molar volumes, the fluidity (reciprocal viscosity) increases linearly with molar volume at fixed temperature and weakly with temperature at fixed volume. We have described this behavior with simple empirical equations and have compared the data of Shankland and of Ripple with them. The data of Ripple are in good agreement with our data for both fluids.

KEY WORDS: chlorotetrafluoroethane; compressed fluid; fluidity; saturated liquid; torsional crystal viscometer; viscosity.

1. INTRODUCTION

Accurate mathematical models are needed for calculating the viscosities of substitutes for chlorofluorocarbon fluids. As both accurate data and an accurate molecular theory of liquids are lacking, we have measured the dependences of the viscosities of saturated and compressed fluid 1-chloro-1,2,2,2-tetrafluoroethane (R124) and pentafluoroethane (R125) on temperature and on pressure.

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2. APPARATUS AND PROCEDURES

The method, apparatus, and procedures are essentially the same as described in Refs. 1 and 2. Two torsional crystal viscometers were used to cover the temperature range 120–420 K. A torsional crystal, approximately 5 cm long and 0.5 cm in diameter [1], was used at temperatures below 320 K. Another torsional crystal, approximately 5 cm long and 0.3 cm in diameter [2], was used at temperatures above 320 K.

The fluids were analyzed for halocarbon impurities and water using gas chromatographic methods. The R124 sample contained 0.02 mol% carbon dioxide, 0.02% air, and about 21 ppm water. According to the supplier the R125 sample contained 0.267% R115, 2.0 ppm carbon dioxide, and 0.4 ppm carbon monoxide. Molecular sieves were placed in the supply cylinders to remove residual water. Measurements were made on several samples of each fluid with good repeatability. Viscosities, η, were obtained [1, 2] from measured resonance curve bandwidths, Δf, and resonant frequencies, f, using the equation [3]

$$\eta = \frac{\pi f}{\rho} \left[\frac{M}{S} \right]^2 \left[\frac{\Delta f}{f} - \frac{\Delta f_{\text{vac}}}{f_{\text{vac}}} \right]^2 \qquad (1)$$

where ρ is the fluid density, M is the mass of the crystal, and S is the surface area of the crystal. Densities were calculated from measured temperatures and pressures and an extended corresponding-states model [4]. The errors in the densities are estimated to be smaller than 1%.

3. RESULTS AND DISCUSSION

3.1. 1-Chloro-1,2,2,2-tetrafluoroethane (R124)

Measurements of the viscosity of saturated liquid R124, at temperatures between 120 and 385 K, are given in Table I. Measurements of the viscosity of compressed fluid R124, at temperatures between 150 and 420 K and at pressures to 50 MPa, are given in Table II. The dependence of the viscosity of R124 on density is shown in Fig. 1. At high densities, there is a transition from a weak dependence on density to a very strong dependence. The dependence of the fluidity (reciprocal viscosity) [5–7] on the molar volume is shown in Fig. 2. The fluidity increases nearly linearly with molar volume in this volume range. There is a small dependence on temperature at fixed volume. There is no transition in the volume dependence corresponding to the transition in the density dependence in Fig. 1.

Our data for saturated and compressed liquid R124 have been correlated using an empirical fluidity–volume–temperature equation,

$$\eta^{-1} = 228.0\,[\exp(-3.88 \times 10^4/T^2)](V - 0.0742) - 980.0\{\exp[-71.43(0.244 - V)]\} \tag{2}$$

where η is the viscosity in mPa · s, T is the temperature in K, and V is the molar volume in $dm^3 \cdot mol^{-1}$. The differences between our data and Eq. (2)

Table I. Viscosity of Saturated Liquid Chloro-1,2,2,2-tetrafluorethane (R124)

Temperature (K)	Density ($mol \cdot dm^{-3}$)	Viscosity (mPa · s)
120.00	12.89	42.44
130.00	12.82	17.71
140.00	12.72	8.68
150.00	12.59	5.252
160.00	12.44	3.444
170.00	12.29	2.386
180.00	12.13	1.791
190.00	11.97	1.401
200.00	11.80	1.112
210.00	11.64	0.904
220.00	11.47	0.753
230.00	11.29	0.645
240.00	11.11	0.557
250.00	10.93	0.474
260.00	10.74	0.415
270.00	10.54	0.370
280.00	10.33	0.322
290.00	10.11	0.287
300.00	9.87	0.254
310.00	9.62	0.222
320.00	9.36	0.200
330.00	9.07	0.178
340.00	8.75	0.156
345.00	8.57	0.146
350.00	8.39	0.137
355.00	8.19	0.128
360.00	7.98	0.119
365.00	7.75	0.111
370.00	7.49	0.104
375.00	7.20	0.096
380.00	6.85	0.087
385.00	6.42	0.080

Table II. Viscosity of Compressed Fluid 1-Chloro-1,2,2,2-tetrafluorothane (R124)

Temperature (K)	Pressure (MPa)	Density ($mol \cdot dm^{-3}$)	Viscosity ($mPa \cdot s$)
420.00	56.17	9.37	0.210
	50.08	9.65	0.197
	41.25	9.27	0.176
	34.66	9.02	0.160
	27.66	8.86	0.142
	20.71	8.24	0.122
	16.83	7.92	0.109
	13.81	7.59	0.100
	10.44	7.07	0.0854
	7.212	6.12	0.0621
	6.081	5.35	0.0514
	5.111	3.68	0.0356
	3.465	1.51	0.0203
370.00	54.15	10.31	0.260
	48.26	10.18	0.245
	41.59	10.01	0.229
	34.63	9.80	0.214
	27.41	9.56	0.195
	20.63	9.27	0.176
	13.76	8.90	0.155
	7.167	8.35	0.128
	3.746	7.86	0.113
350.00	52.79	10.54	0.300
	48.48	10.45	0.286
	41.46	10.29	0.264
	34.46	10.11	0.247
	27.59	9.90	0.227
	20.76	9.66	0.206
	13.83	9.36	0.185
	9.971	9.14	0.170
	7.046	8.95	0.159
	3.533	8.64	0.147
320.00	30.41	10.46	0.307
	27.41	10.39	0.299
	23.99	10.30	0.286
	20.71	10.20	0.274
	17.06	10.09	0.262
	13.68	9.97	0.251
	10.37	9.85	0.240
	6.780	9.69	0.225
	3.528	9.53	0.211
300.00	30.50	10.77	0.373
	27.29	10.70	0.359
	23.83	10.62	0.345
	20.76	10.55	0.334
	16.96	10.45	0.321
	13.74	10.36	0.306
	10.38	10.25	0.293
	6.934	10.14	0.282
	3.485	10.01	0.268

Table II. *(Continued)*

Temperature (K)	Pressure (MPa)	Density ($mol \cdot dm^{-3}$)	Viscosity ($mPa \cdot s$)
270.00	30.83	11.21	0.509
	27.51	11.16	0.492
	24.06	11.09	0.473
	20.68	11.03	0.462
	17.28	10.96	0.446
	13.81	10.89	0.427
	10.44	10.81	0.412
	6.923	10.72	0.398
	3.441	10.63	0.378
250.00	30.35	11.49	0.641
	27.61	11.45	0.622
	24.20	11.39	0.611
	20.56	11.34	0.586
	17.26	11.28	0.575
	13.80	11.22	0.552
	10.36	11.15	0.528
	6.991	11.08	0.512
	3.522	11.01	0.496
220.00	27.53	11.87	0.993
	24.35	11.83	0.953
	20.59	11.78	0.925
	17.19	11.74	0.897
	13.67	11.69	0.870
	10.32	11.64	0.853
	7.005	11.58	0.816
	3.439	11.53	0.781
200.00	29.79	12.18	1.48
	27.50	12.15	1.44
	24.11	12.12	1.41
	20.72	12.08	1.37
	17.26	12.03	1.33
	13.80	11.99	1.27
	10.39	11.95	1.25
	6.866	11.90	1.19
	3.494	11.85	1.15
170.00	30.85	12.60	3.28
	27.44	12.57	3.17
	23.96	12.54	3.07
	20.84	12.51	3.02
	17.32	12.47	2.97
	13.78	12.44	2.76
	10.51	12.40	2.67
	6.980	12.37	2.60
	3.443	12.33	2.47
150.00	31.04	12.86	7.45
	27.14	12.82	7.13
	23.87	12.80	6.81
	20.69	12.77	6.61
	17.21	12.74	6.40
	13.02	12.71	6.21
	10.41	12.68	5.91
	6.891	12.65	5.72
	3.520	12.62	5.43

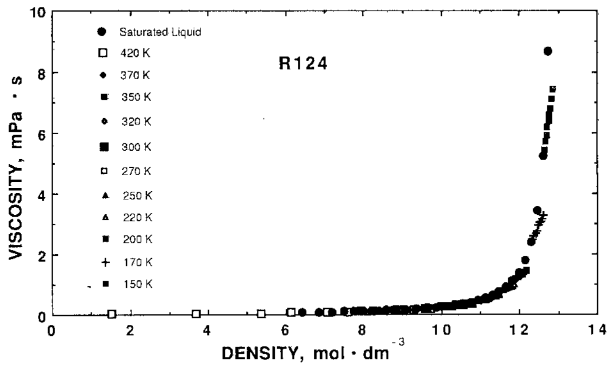

Fig. 1. Dependence of the viscosity of saturated and compressed fluid R124 on density.

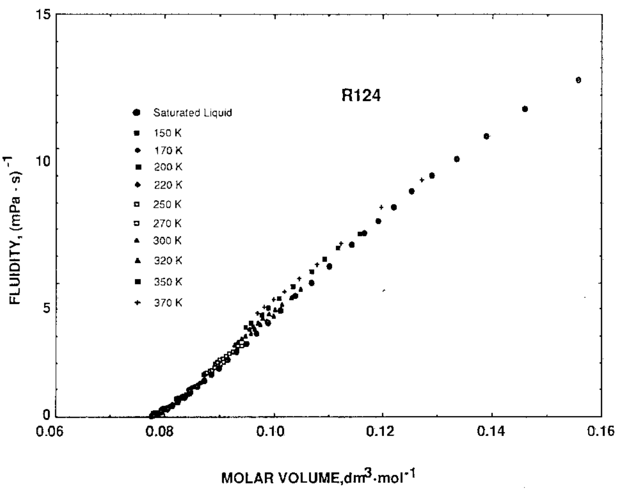

Fig. 2. Dependence of the fluidity of saturated and compressed fluid R124 on molar volume.

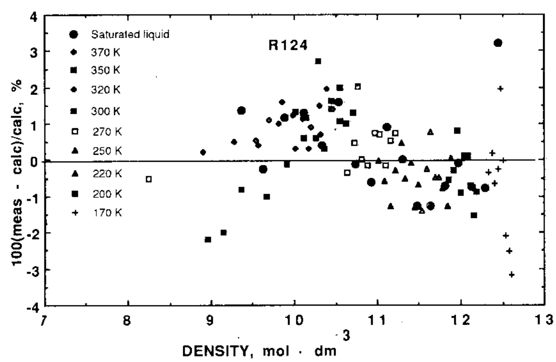

Fig. 3. Comparison of our data for saturated and compressed liquid R124 with Eq. (2).

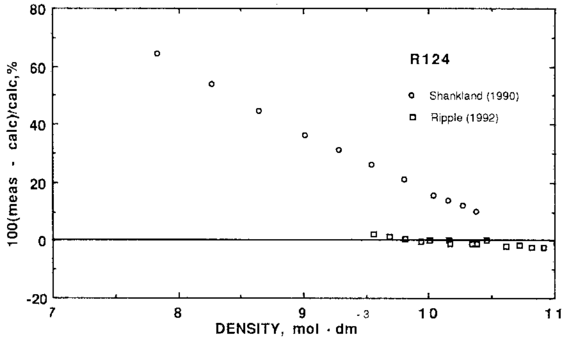

Fig. 4. Comparison of Shankland's data [8] and Ripple's data [9] for saturated liquid R124 with Eq. (2).

Table III. Viscosity of Saturated Liquid Pentafluoroethane (R125)

Temperature (K)	Density ($mol \cdot dm^{-3}$)	Viscosity ($mPa \cdot s$)
176.00	13.89	1.099
180.00	13.79	0.996
185.00	13.66	0.889
190.00	13.53	0.787
195.00	13.40	0.719
200.00	13.27	0.640
205.00	13.14	0.590
210.00	13.00	0.529
215.00	12.87	0.489
220.00	12.73	0.445
225.00	12.58	0.412
230.00	12.44	0.378
235.00	12.29	0.353
240.00	12.14	0.325
245.00	12.98	0.306
250.00	11.82	0.282
255.00	11.66	0.262
260.00	11.48	0.247
265.00	11.31	0.227
270.00	11.12	0.215
275.00	10.93	0.199
280.00	10.73	0.184
285.00	10.52	0.170
290.00	10.29	0.160
295.00	10.06	0.148
300.00	9.80	0.138
305.00	9.53	0.126
310.00	9.23	0.116
315.00	8.90	0.105
320.00	8.52	0.096
325.00	8.08	0.089
330.00	7.51	0.075

Table IV. Viscosity of Compressed Fluid Pentafluoroethane (R125)

Temperature (K)	Pressure (MPa)	Density ($mol \cdot dm^{-3}$)	Viscosity ($mPa \cdot s$)
420.00	53.07	10.12	0.142
	49.41	9.95	0.136
	45.21	9.75	0.128
	42.23	9.59	0.122
	38.26	9.35	0.114
	34.75	9.13	0.107
	31.37	8.87	0.099
	27.75	8.55	0.092
	24.38	8.20	0.0840
	20.80	7.75	0.0735
	18.11	7.32	0.0659
	15.40	6.759	0.0572
	13.90	6.355	0.0514
	10.65	5.077	0.0396
	8.05	3.571	0.0319
	7.857	3.452	0.0311
	6.346	2.579	0.0242
	6.206	2.502	0.0239
	4.591	1.685	0.0204
370.00	52.14	10.97	0.186
	48.22	10.83	0.177
	44.82	10.69	0.171
	41.34	10.55	0.163
	38.62	10.42	0.157
	34.94	10.24	0.149
	31.27	10.04	0.139
	27.65	9.81	0.132
	24.40	9.57	0.123
	20.87	9.27	0.112
	17.34	8.89	0.101
	13.93	8.420	0.0878
	10.77	7.771	0.0751
	7.831	6.634	0.0557
	6.285	5.123	0.0446
	5.117	3.217	0.0268
	3.307	1.497	0.0186
335.00	44.39	11.37	0.219
	41.47	11.27	0.207
	37.80	11.14	0.200
	34.74	11.02	0.192
	31.12	10.86	0.183
	27.62	10.69	0.172
	24.26	10.51	0.162
	20.51	10.28	0.152
	17.21	10.04	0.142
	14.03	9.77	0.130
	10.25	9.34	0.116
	9.50	9.24	0.112
	7.667	8.93	0.104
	6.851	8.76	0.101
	5.219	8.31	0.088
	3.848	7.59	0.074

Table IV. *(Continued)*

Temperature (K)	Pressure (MPa)	Density ($mol \cdot dm^{-3}$)	Viscosity ($mPa \cdot s$)
320.00	31.02	11.21	0.205
	27.61	11.06	0.195
	24.32	10.91	0.185
	20.92	10.73	0.175
	17.33	10.52	0.163
	13.85	10.27	0.154
	10.60	9.99	0.139
	6.920	9.57	0.123
	3.529	8.93	0.104
300.00	29.22	11.61	0.235
	27.03	11.53	0.228
	23.93	11.41	0.220
	20.81	11.27	0.213
	17.20	11.10	0.201
	13.72	10.91	0.188
	10.33	10.70	0.176
	6.910	10.43	0.162
	3.438	10.08	0.147
270.00	30.57	12.33	0.328
	28.92	12.29	0.321
	27.50	12.25	0.315
	21.76	12.07	0.296
	20.69	12.04	0.289
	17.24	11.92	0.285
	13.91	11.80	0.269
	10.23	11.64	0.255
	7.101	11.50	0.244
	3.626	11.31	0.224
250.00	30.75	12.78	0.409
	27.49	12.70	0.401
	24.16	12.62	0.386
	20.92	12.53	0.374
	17.36	12.43	0.357
	13.90	12.33	0.343
	10.51	12.22	0.326
	6.987	12.10	0.313
	3.518	11.96	0.297
220.00	29.28	13.39	0.618
	27.52	13.36	0.604
	23.04	13.27	0.585
	19.69	13.20	0.566
	17.38	13.16	0.548
	13.82	13.08	0.527
	9.81	12.98	0.502
	6.896	12.91	0.491
	3.458	12.82	0.471
200.00	23.35	13.72	0.825
	20.77	13.68	0.804
	17.49	13.62	0.776
	12.19	13.52	0.743
	10.50	13.49	0.730
	6.995	13.42	0.697
	3.558	13.35	0.664

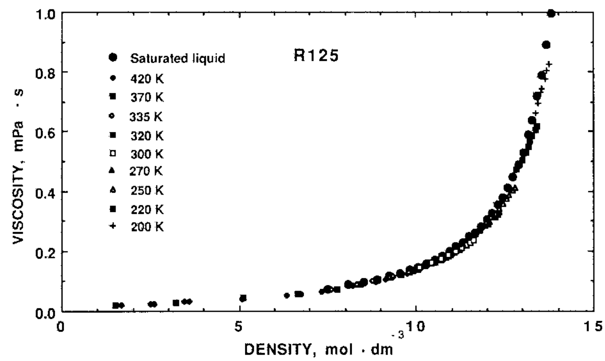

Fig. 5. Dependence of the viscosity of saturated and compressed fluid R125 on density.

are shown in Fig. 3. The estimated precision of our data is about ±3%. The saturated liquid viscosity data of Shankland [8] and Ripple [9] are compared with Eq. (2) in Fig. 4. The Ripple data are in good agreement (about 3%) with Eq. (2). The Shankland data differ from Eq. (2) by more than 10%.

3.2. Pentafluoroethane (R125)

Measurements of the viscosity of saturated liquid pentafluoroethane (R125), at temperatures between 176 and 330 K, are given in Table III. Measurements of the viscosity of compressed fluid R125, at temperatures between 200 and 420 K and at pressures to 50 MPa, are given in Table IV. The dependence of the viscosity of saturated and compressed fluid R125 on

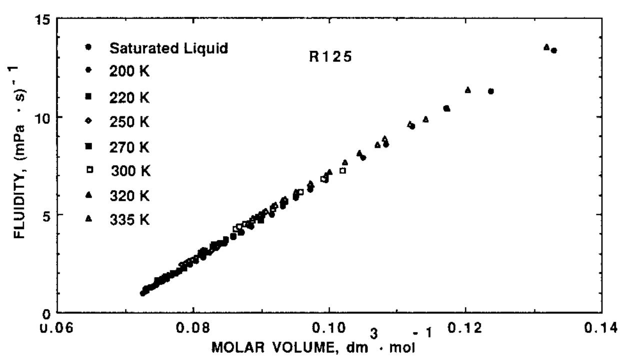

Fig. 6. Dependence of the fluidity of saturated and compressed liquid R125 on molar volume.

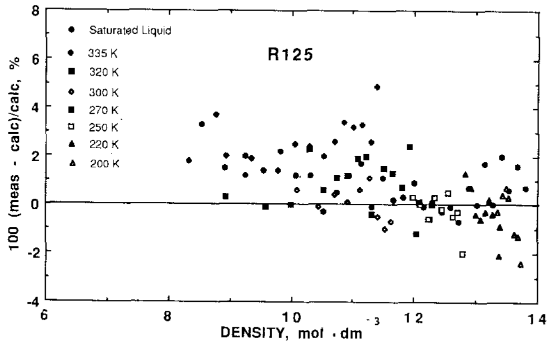

Fig. 7. Comparison of our data for saturated and compressed liquid R125 with Eq. (3).

density is shown in Fig. 5. This figure shows the range of our data for R125. The dependences of the viscosity on density and temperature are similar to those for R124. The dependence of the fluidity of saturated and compressed liquid R125 on molar volume is shown in Fig. 6. This dependence is also similar to that for R124.

Our data for saturated and compressed liquid R125 have been correlated with an empirical fluidity–volume–temperature equation,

$$\eta^{-1} = [250.0(\text{ex0} - 2.00 \times 10^4/T^2)](V - 0.0650) \qquad (3)$$

where η is the viscosity in mPa · s, T is the temperature in K, and V is the molar volume in $dm^3 \cdot mol^{-1}$. The differences between our data and Eq. (3) are shown in Fig. 7. The estimated precision of our data is about $\pm 3\%$. The saturated liquid viscosity data of Shankland [8] and Ripple [9] are compared with Eq. (3) in Fig. 8. The Ripple data are in good agreement with Eq. (3). The Shankland data differ from Eq. (3) by more than 25%.

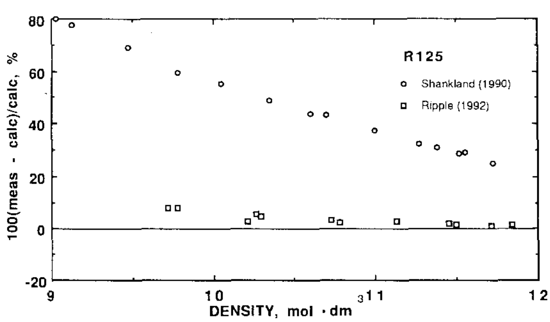

Fig. 8. Comparison of Shankland's data [8] and Ripple's data [9] for saturated liquid R125 with Eq. (3).

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REFERENCES

1. W. M. Haynes, *Physica* **108A**:143 (1973).
2. D. E. Diller and N. V. Frederick, *Int. J. Thermophys.* **10**:145 (1989).
3. B. Welber, *Phys. Rev.* **119**:1816 (1960).
4. M. L. Huber and J. F. Ely, ASHRAE-Purdue Conference Proceedings, July 17–20, 1990.
5. A. J. Batschinski, *Z. Phys. Chem.* **84**:643 (1913).
6. J. M. Hildebrand, *Viscosity and Diffusivity* (Wiley, New York, 1977).
7. D. E. Diller, *High Temp. High Press.* **17**:139 (1985).
8. I. R. Shankland, presented at the AIChE Spring National Meeting, Orlando, FL, Mar. 18–22, 1990.
9. D. C. Ripple, Unpublished data, Thermophysics Division, National Institute of Standards and Technology, Gaithersburg, MD (1992).